IMPEDANCE STUDY FOR THE TPS STORAGE RING

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Abstract

Taiwan Photon Source (TPS) is a new third generation synchrotron storage ring which will be built at the present site of the NSRRC. The paper summarizes results of the impedance studies of the storage ring vacuum components for the TPS project. The main goal of this work was to support the design of the vacuum chamber and, at the same time, to get a detailed model of the machine impedance, which can be used later for detail studies of collective effects. Wake potentials and impedances for each component of the storage ring have been simulated.

INTRODUCTION

Modern particle accelerators and storage rings, whether used for high-energy physics or as synchrotron light sources, require particle beams with the highest possible intensity. In order to achieve optimum performance, a good understanding is required of the interaction of the charged particle beams with the surrounding structures.

This interaction can be described by wake fields in the time domain, or equivalently by impedances in the frequency domain. These quantities need to be known at least approximately in order to estimate the thresholds of instabilities and other collective effects, which may limit the achievable beam current.

The calculation of impedances and wake fields for a complete accelerator is practically impossible due to enormous complexity of such a task. The usual approach is to calculate impedances of separate components and to add their individual contributions [1].

Extensive calculations have been performed of wake fields produced by the electron bunch in the storage ring. 3-D electromagnetic field simulator GdfidL [2] and 2-D numerical code ABCI [3] have been used for this purpose. Geometries of the components in most cases have been imported into GdfidL using stereolithography (STL) files. The calculation have been performed assuming Gaussian bunch with rms length $\sigma_z = 3$ mm (actual equilibrium rms bunch length in the TPS storage ring is 2.86 mm). Uniform mesh has been used in simulations: mesh size was equal in longitudinal and transversal directions. Maximum mesh size used in simulations has been smaller than $\sigma_z/10$. Weiland's criterion ($\delta_z < \sqrt{\sigma_z^3/L}$) [4] has also been satisfied to avoid dispersion errors (this is especially important for long structures like cavity or bending chamber). Usually the wake potentials have been computed over a distance of 1 m behind the bunch. For structures with resonance behavior of electromagnetic fields, such as cavities or flanges, the wake potentials have been computed over a distance of 10 m or more to ensure good frequency resolution of the impedance.

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STORAGE RING COMPONENTS

Most of the components studied are fairly common and have been successfully used in many machines. Nevertheless, detailed studies have been done in order to optimize impedance of some components and to clarify dependence of the impedance on the geometry of these components.

There should be more than two hundred photon absorbers of different height installed in the ring. Dependences of impedance and loss factors on absorbers' height have been studied showing that higher absorbers cause bigger broad-band impedance and loss factors. This dependence has an almost linear shape.

Titanium bellows have been proposed for the TPS storage ring. Radio frequency (RF) shielding of bellows has long slot in its solid part. Two types of bellows have been studied: with two such slots and with only one slot. Results of simulations show that there is only minor difference in the shape of wakes from bellows with two and one slot. This means that the contribution to the impedance from longitudinal slots in the RF shielding is insignificant.

In a bending chamber, electron beam moves along curvilinear trajectory. Simulation of curvilinear structures is impossible in GdfidL. For this reason, simplified rectilinear model of the TPS bending chamber including elliptical beam channel, pumping ports, beam position monitor (BPM), and the crotch absorber has been created (Fig. 1). Analysis of eigenwaves performed with GdfidL shows that there are no longitudinal resonant modes excited in the structure.

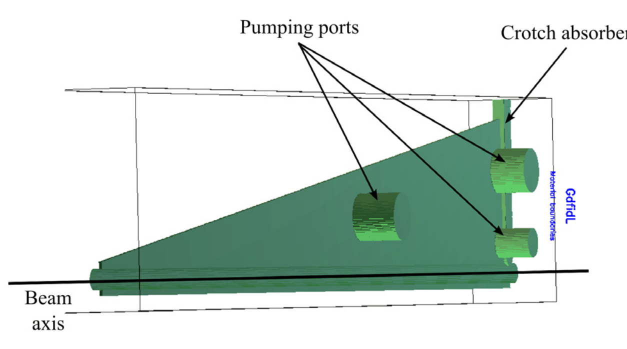

Figure 1: Simplified rectilinear model of the TPS bending chamber.

Aluminum flanges with RF bridge will be used in the beam duct chambers of the TPS storage ring. Even with

RF shielding present, the gap between flanges represents a very narrow cylindrical cavity of complicated geometry. An electron bunch excites resonant modes in the gap between flanges and electromagnetic field can store significant amount of energy in the structure. Electromagnetic code GdfidL has been used to study eigenwaves in the flange system. Analysis shows that the lowest resonance frequency of the cavity is above cut-off of the waveguide. This means that cavity doesn't have trapped modes and energy of exited resonant modes can propagate along the elliptical waveguide. This fact is also confirmed by the low quality factor of the resonances.

GdfidL was not able to handle entire STL file of the gate valve due to its complexity. Only the most important part of the STL data has been used to create a simplified model of the TPS sector gate valve with comb-type RF shielding.

Four superconducting RF (SRF) cavities are planned for the TPS storage ring to maintain the beam current and energy. The cavities and cavity tapers have been simulated separately. Only the fundamental mode of the cavity has high quality factor and hence high impedance. The rest of the modes have low quality factors due to energy leakage to the beam pipes. The cavity have also been simulated in ABCI using a very fine mesh to crosscheck the result obtained with GdfidL. Cavity taper represents a linear transition from circular to elliptical cross section of the beam pipe. Wake fields produced by the cavity tapers are rather big. This results in relatively high broad-band impedance of this structure. Some studies have been done to check whether a smother transition will reduce impedance of this structure. The wake potentials produced by original and optimized tapers are quite similar but amplitude of the wake potential from the smooth transition is slightly smaller. Overall, the smooth transition has better characteristics, but the difference between these two cases is insignificant.

There are several kinds of tapers proposed for the TPS storage ring besides SRF cavity tapers. Insertion devices (ID) chambers have been studied in detail. This structure represents tapered transition from elliptical beam pipe to beam pipe with race-track cross section. Tapered structures of ID chambers were simulated in GdfidL assuming different dimensions of the beam-pipe with race-track cross-section. Results of simulations show that the smaller is the gap of the ID chamber the higher are its loss factor and impedance (Fig. 2). In the final design, the slope of the tapers should be chosen with care to meet the broad-band impedance goals of the ring.

Among other elements which have been simulated are chamber with pumping ports, injection section taper, and two kinds of BPMs.

Longitudinal resistive-wall (RW) wake potentials for a Gaussian bunch have been calculated using Piwinski's formula [5] assuming circular Aluminum beam pipe. The RW model of the TPS storage ring consists of: 48 m of Al beam pipe with $r = 5$ mm, 60 m with $r = 10$ mm, and 410.4 m with $r = 15$ mm.

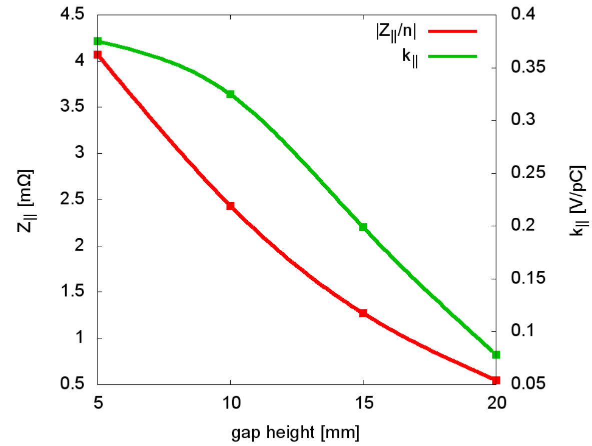

Figure 2: Broad-band impedance and longitudinal loss factor of ID chamber vs. vertical gap of the chamber.

IMPEDANCE BUDGET

To calculate broad-band impedance, a model developed by Bane and Heifets [6, 7] has been used. The wake potential should be classified as inductive, resistive or capacitive (cavity-like). Once classified, an analytic expression can be used to relate the maximum of the wake potential to the broad-band impedance.

Figure 3 shows wakes from several groups of elements as well as the total wake. One can see that the most significant wake potentials are produced by bellows, flanges and tapers.

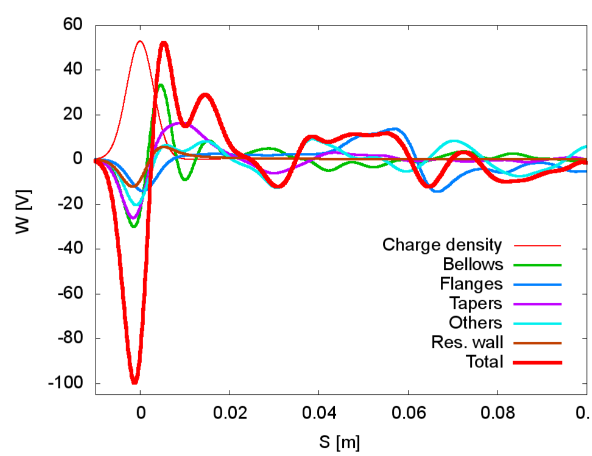

Figure 3: Longitudinal wake potential as function of distance from bunch for various groups of elements.

Figure 4 shows real and imaginary parts of the longitudinal geometrical impedance of the TPS storage ring. Tapers contribute to the impedance mainly in the frequency ranges 5–20 GHz (real part) and 5 GHz (imaginary part), bellows significantly enhance impedance in the frequency ranges 20–30 GHz (real part) and 10–30 GHz (imaginary part). BPMs and flanges are responsible for numerous peaks of

Table 1: Impedance budget for the TPS storage ring.

Components	$\lvert Z_{\parallel}/n\rvert, \Omega$	$k_{\parallel}, V/pC$	$k_x, V/pC/m$	$k_y, V/pC/m$	N
Σ Absorbers (injection section)	9.27×10^{-6}	1.36×10^{-3}	4.79×10^{-2}	4.99×10^{-11}	1
Σ Absorbers (straight sections)	3.62×10^{-5}	6.42×10^{-3}	1.78×10^{-1}	6.71×10^{-11}	24
Bellows (straight sections)	3.14×10^{-4}	6.12×10^{-2}	7.53×10^{-3}	1.99×10^{-1}	144
Bending chamber	1.04×10^{-5}	2.75×10^{-3}	8.70×10^{-2}	1.35×10^{-3}	48
BPM, primary (long straight sections)	1.72×10^{-4}	6.39×10^{-2}	1.26×10^{-5}	1.95×10^{-6}	48
BPM, standard (achromatic sections)	8.50×10^{-5}	3.35×10^{-2}	1.24×10^{-3}	9.00×10^{-4}	168
Flange (straight sections)	3.57×10^{-4}	5.82×10^{-2}	2.57×10^{-4}	3.15×10^{-4}	168
Gate valve (straight sections)	5.99×10^{-5}	1.34×10^{-2}	4.66×10^{-2}	1.11×10^{-2}	56
Pumping slots chamber (straight sections)	1.36×10^{-5}	1.17×10^{-3}	2.53×10^{-10}	1.37×10^{-11}	96
SRF Cavity (500MHz)	4.44×10^{-2}	4.10×10^{-1}	2.26×10^{-4}	1.81×10^{-5}	4
SRF Cavity Tapers	1.09×10^{-2}	4.84	2.03×10^{-3}	2.08×10^{-1}	2
Taper (injection section)	2.57×10^{-6}	7.15×10^{-5}	3.59×10^{-2}	8.17×10^{-9}	1
Taper (straight sections, 20 mm gap)	5.46×10^{-4}	7.82×10^{-2}	2.65×10^{-2}	1.87×10^{-1}	24
Taper, ID (straight sections, 10 mm gap)	2.43×10^{-3}	3.25×10^{-1}	2.23×10^{-4}	3.35×10^{-1}	4
Resistive wall	1.84×10^{-2}	5.29	–	–	–
Total	3.74×10^{-1}	4.82×10^{1}	1.31×10^{1}	3.58×10^{1}	987

impedance in both real and imaginary parts. Impedance of the SRF cavity is localized in the frequency range 500MHz.

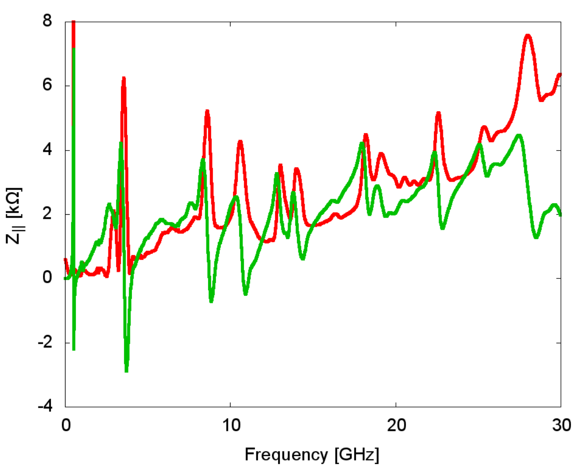

Figure 4: Real and imaginary parts of the longitudinal geometrical impedance of the TPS storage ring.

Impedance budget of the TPS storage ring obtained with a 3 mm bunch is shown in Table 1, where values per element of the longitudinal broad-band impedance, longitudinal loss factor, and transverse kick factors are presented. The most numerous elements in the storage ring are bellows, BPMs, flanges, and pumping ports chambers. Total broad-band impedance obtained so far is about $0.4\ \Omega$. Total longitudinal loss factor is about 48 V/pC. In terms of power losses, this corresponds to 22 kW.

Figure 5 shows contributions to the total impedance (in terms of $k_{||}$) from different groups of elements. One can see that major contributors to the impedance of the ring are tapers, flanges, bellows, and BPMs. Resistive wall accounts for about 11 percent of the total impedance.

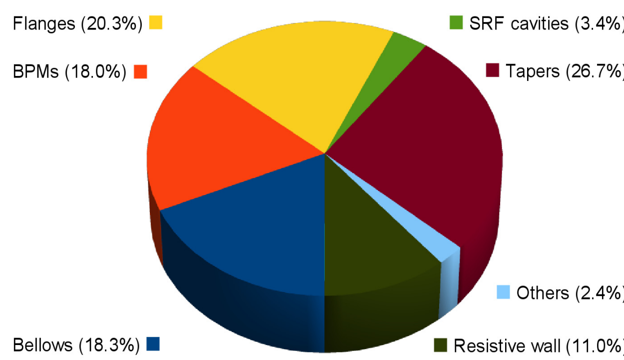

Figure 5: Contribution of the components to the total broad-band impedance (in terms of $k_{||}$.)

CONCLUSION

The TPS storage ring broad-band impedance and loss factor have been calculated. Contributions to the total broad-band impedance from different groups of elements have been found. Frequency content of the total longitudinal impedance has been studied, and major contributors in different frequency ranges have been determined.

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